TURKEY FLAT, USA

SITE EFFECTS TEST AREA

Report 1

Needs, Goals, and Objectives

This paper was originally prepared in September 1986, and was later presented at the Electric Power Research Institute's workshop on Ground Motions in Eastern North America. It was published in the workshop proceedings in August 1988 under the Title: "The Design and Operation of A Test-Site Near Parkfield, California To Compare and Test Methods of Estimating The Effect of Surface Geology on Seismic Motion".

The Design and Operation of A Test-Site Near Parkfield, California To Compare and Test Methods of Estimating The Effect of Surface Geology on Seismic Motion

Brian E. Tucker
and
Charles R. Real

I. INTRODUCTION

The September 19, 1985 Mexican Earthquake is our most recent, striking reminder that the effects of surface geology on seismic motions can be large. For both the mainshock (M 8.1) and its major aftershock (M 7.5), it appears that damage in the coastal cities, near the epicenters, was comparable to or less than that in Mexico, some 250 miles inland. In addition, damage varied greatly within the confines of Mexico City. Since there is no reason to believe that, in general, construction is better in the coastal cities than in Mexico City and no better in one part of the city than in others, soil conditions in the capital are considered important in explaining the observed variation in damage.

That the effects of surface geology on seismic waves can be large has long been accepted. Questions that remain to be satisfactorily answered include: How do these effects depend on the amplitude, azimuth, and incidence angle of the input signal? How good are theoretical and experimental methods of estimating these effects? How do estimates from different methods compare with each other

---

California Department of Conservation, Division of Mines and Geology

and with actual observations? Do different workers, using the same method, estimate the same effects?

Despite the active research in the theory and observation of geologic site effects over the last ten years, not much progress has been made in answering the above questions. We now have, compared with ten years ago, much more sophisticated, accurate, and labor-saving experimental tools for observing site effects. There are also now computer and physical modelling techniques that allow calculations of sites with 3-dimensional structures and rheologic properties varying with depth and frequency. These techniques have, however, not yet been rigorously compared with each other nor with observations.

Until these methods of estimating site effects are systematically assessed, they cannot be used confidently to mitigate earthquake hazards. Authors of building codes, geotechnical engineers, structural engineers, and land-use planners must know the reliability and repeatability of these methods. Performing a set of experiments that will objectively and systematically compare and test the various experimental and theoretical methods of estimating site effects is a rather unglamorous, time-consuming, and expensive task. It is, however, needed.

The above paragraphs outline a recent discussion of members of a working group of the Committee on Earthquake Hazard Assessment of the International Association of Seismology and Physics of the Earth's Interior (IASPEI). As an outgrowth of that discussion, IASPEI, in its August 1985 meeting, passed a resolution that invited the International Association of Earthquake Engineers (IAEE) to form a joint working group on the effects of surface geology on seismic motion and to have as part of its experimental activities the establishment of several test areas throughout the world where methods of estimating site effects can be compared and tested. This joint working group is now being formed and will have its first meeting during the next IASPEI conference in August 1987 in Vancouver, Canada. The working group will attempt to develop a plan for the establishment of several such test sites throughout the world; this program might be considered as part of the proposed International Decade of Hazard Reduction.

The project outline below will partially fulfill IASPEI's recommendation, and may serve as a model upon which improvements can be made in future test areas elsewhere in the world.

II. THE CALIFORNIA TEST AREA AND ITS INSTRUMENTATION

A. Location

A test area has been established at Turkey Flat, a thin alluvial valley near Parkfield, California (Figures 1 and 2). There, the United States Geological Survey has predicted that a moderate-sized (M 5-1/2) earthquake will occur on the Parkfield segment of the San Andreas Fault in the next four years. Using the strong-motion records of the 1966 Parkfield event (M 5.6), one can estimate that Turkey Flat, about 10 km from the San Andreas, will probably experience strong ground motion (perhaps exceeding 1/2 g acceleration) during the predicted event.

FIGURE 1

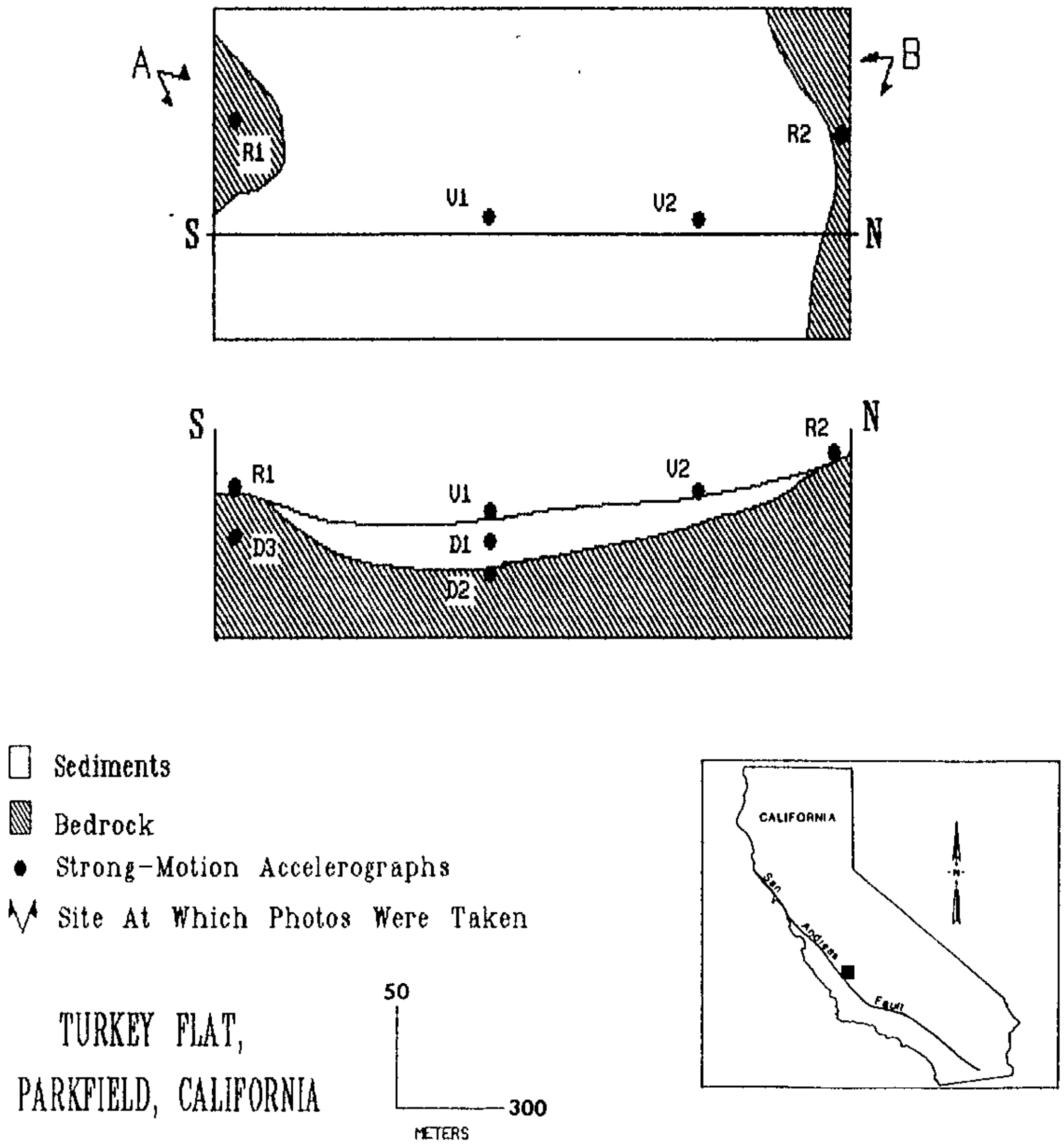

A
B
R1
R2
V1
V2
S
N
D1
D2
D3
Sediments
Bedrock
Strong-Motion Accelerographs
Site At Which Photos Were Taken
TURKEY FLAT,
PARKFIELD, CALIFORNIA
50
300
METERS
CALIFORNIA
San Andreas Fault
N

FIGURE 2

Photo A
(line A-A', in Figure 1, lies along the fence in this photo)

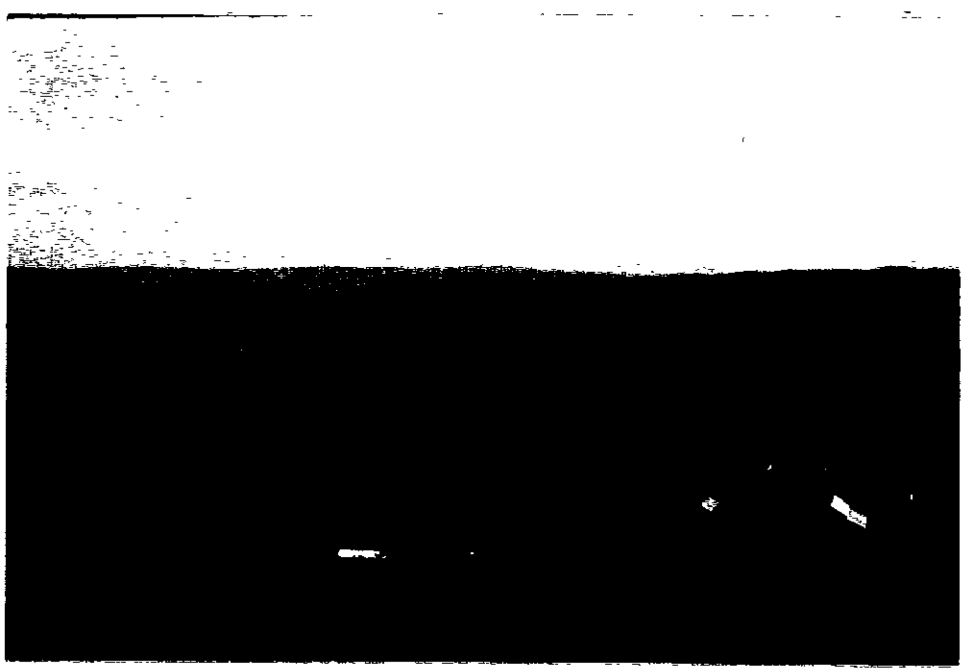


Photo B
(line A-A', in Figure 1, separates the light and dark green pastures on this photo)

(The sites, at which these photos were taken on Turkey Flat, are indicated on Figure 1; these photos were taken in different seasons.)

B. Characteristics

The selection of the test area was based not only on proximity to the Parkfield segment of the San Andreas fault but also on the characteristics of the surface geology: the test area has site conditions that are common in California and elsewhere in the world. Turkey Flat is a relatively flat alluvial valley with maximum sediment thickness of about 20 meters, a maximum width of about 2 km, a length of about 8 km, and is bordered and underlain by hard rock. This geographical setting typifies areas that commonly undergo urban development.

C. Geotechnical Surveying

In order to provide input parameters to theoretical models, extensive and accurate surveying of the test area's geotechnical properties is currently in progress. Seven of the leading U.S. and two major Japanese geotechnical firms are conducting field operations, laboratory analyses, and data interpretation services. Measurements include downhole, crosshole, suspension logging, seismic refraction and reflection, and vertical seismic profiling for P- and S-wave velocity structure and attenuation; electric and nuclear logging for lithology and density; and, sampling for laboratory determination of soil properties. State-of-the-art equipment and techniques are being employed as well as industry standard field and laboratory soil tests. Redundancy in testing is planned so results for the same tests by different investigators and different methods can be compared and a quantitative estimate of uncertainties in the soil properties made. The geotechnical tests being made and the firms making them are summarized on Table I.

TABLE 1. GEOTECHNICAL ACTIVITIES

GEOTECHNICAL TESTS	CON	D&M	CDMG	HLA	LCA	QEST	WCC	PDC	OYO	KC
DRILLING AND SAMPLING			X		X		X	X	X	
STANDARD PENETRATION TEST			X		X		X	X		
WATER TABLE DEPTH			X							
ELECTRICAL									X	
CALIPER									X	
DENSITY (GAMMA-GAMMA)				X					X	
BOREHOLE DEVIATION			X							
BOREHOLE LATERAL LOAD TEST									X	
NATURAL GAMMA				X						
DOWNHOLE VP/VS			X		X	X	X		X	
CROSSHOLE VP/VS				X						
SUSPENSION VP/VS									X	
DOWNHOLE Q (P & S)			X			X			X	X
VERTICAL SEISMIC PROFILING									X	
SEISMIC REFLECTION (P & S)									X	
SEISMIC REFRACTION (P & S)			X						X	
LABORATORY SOIL TESTING	X	X			X		X		X	

CON - Converse
D&M - Dames & Moore
CDMG - California Division of Mines & Geology
HLA - Harding Lawson Associates
LCA - LeRoy Crandall & Associates

QEST - QEST Consultants
WCC - Woodward-Clyde Consultants
PDC - Pitcher Drilling Company
OYO - Oyo Corporation
KC - Kajima Corporation

D. Seismic Instrumentation

The Strong-Motion Instrumentation Program (SMIP), a part of the California Division of Mines and Geology, is installing three-component, digital strong-motion accelerographs at two sites on the sediments and two on the bordering rock. Accelerographs have been installed on the ground surface at these sites and are now operational. Installation of two downhole instruments for the valley and one downhole instrument for the rock sites is scheduled for completion late spring 1987. The deployment of accelerographs is indicated in Figure 1. Records from this array will be collected, processed and distributed by SMIP and will provide the observation of strong-motion with which predictions will be compared. This array is an augmentation of SMIP's existing 40-element strong-motion array located along the Parkfield segment of the San Andreas fault.

III. THE METHODS TO BE COMPARED AND TESTED

It is planned that a variety of the currently-used methods of estimating site effects will be used to predict the response to seismic motion at the proposed site. Some of the classes of methods that may be used are:

1) physical models (e.g., foam rubber and centrifuge models),

2) computer models (e.g., three-dimensional, two dimensional, or one-dimensional mathematical descriptions of the test area using experimentally-determined properties of the substratum),

3) seismic (e.g., measurements of the response of the test sites to micro-tremors, small earthquakes, and man-made explosions).

It is desired that some researchers will use the same method so that a comparison of their estimates can be made to provide a measure of the repeatability of methods.

IV. THE COMPARISON AND TEST

It is planned that each method will be used to predict some measure of the ground motion at each site of the test area. Measures that will be considered are 1) the spectral ratio of motion at a test site with respect to the motion at a reference site; 2) the response spectrum, given the ground motion at a reference site; and 3) the time trace of ground motion, given the trace of the ground motion at a reference site.

The methods will be compared in several ways. First, estimates from various methods will be compared with each other and with actual observations by providing the predictors with an actual observation of weak ground motion at the reference rock sites (R1 and R2 on Figure 1) and asking of each method the predicted motion at each test site (sites V1, V2, D1, D2, and D3). Next, the same test will be made only using an arbitrary strong-motion level (e.g., a recording of the 1966 Parkfield event, scaled to have a peak acceleration of 0.5g) as input from the reference site. These two comparisons will discriminate between the models on the basis of the linearity of the response and thickness of sediment. Finally, after the predicted Parkfield earthquake occurs, the same test will again be repeated only with actual observed strong ground motion records at the reference site as input. Comparisons will then be made between estimated strong ground motion and observed strong ground motion.

V. SCHEDULE

The schedule of activities at the Turkey Flat Test Area is summarized in Figure 3 and each of the activities listed is described in Table II. The overall timeframe of the project is indefinate because completion ultimately requires occurrence of the anticipated Parkfield characterisic earthquake. The schedule of activities prior to recording the Parkfield event, however, is well defined and is summarized here.

Geotechnical field investigations, laboratory soil testing, and interpretation of geotechnical data is underway from Fall of 1986 through the Spring of 1987. Strong-motion accelerographs are also being installed during this period.

A Geotechnical Workshop is planned for June 1987. At this meeting, the organizations that had collected geotechnical data will have an opportunity to present their conclusions. Methods and results will be compared. The structural models of the test area, which each organization deduced from the data, will be presented. One of the most important outputs of this workshop will be some consensus on what is the best "average" structural model. This model will be used by all methods, in the next phase of the program, to predict the seismic response

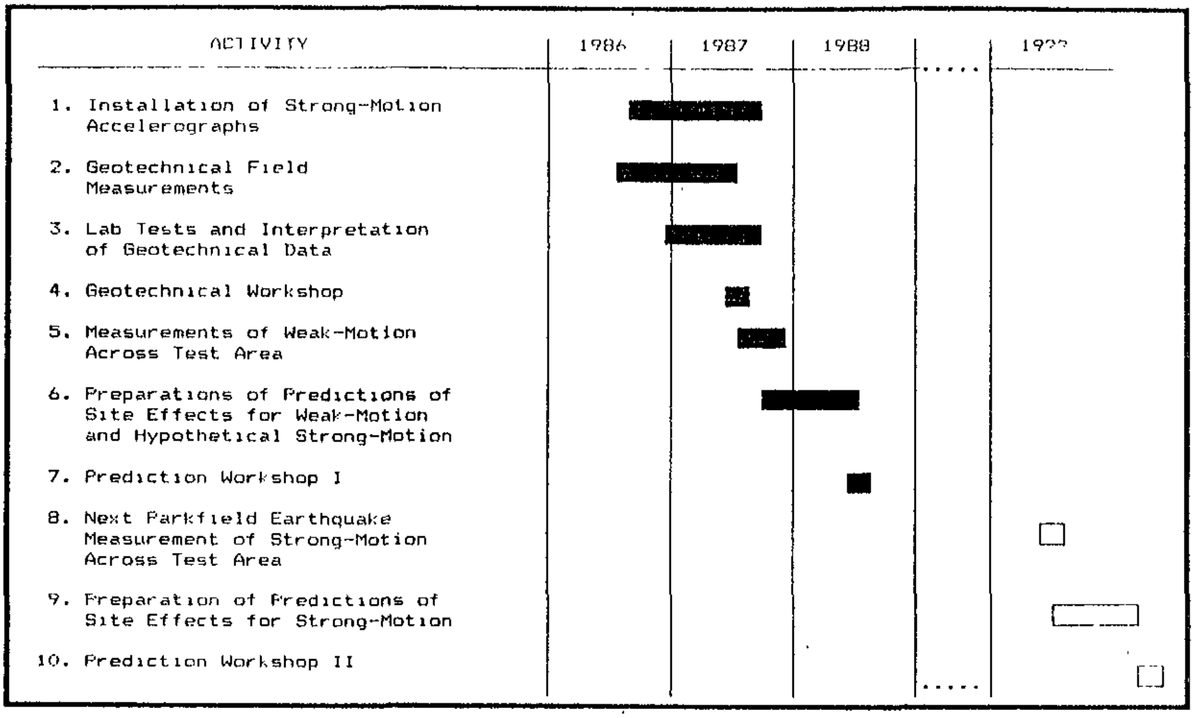
TABLE II

DESCRIPTION OF ACTIVITIES

ACTIVITY	WHEN	WHO	INPUT	PRODUCT	PURPOSE
1) Installation of Strong-Motion Accelerographs	Fall 1986 - Spring 1987	SHIP/DMG		4 surface and 3 down-hole accelerographs (sites V1, V2, D1, D2, D3, R1 and R2 on Figure 1)	
2) Geotechnical Field Measurements	Fall 1986 - Spring 1987	Firms and Organizations listed on Table I		Raw data from tests listed on Table I	
3) Lab Tests and Interpretation of Geotechnical Data	January - May 1987	Firms and Organizations listed on Table I	Raw geotechnical data	2-D structural model of test area	
4) Geotechnical Workshop	June 1987	Firms and Organizations listed on Table I Anyone else interested	Individually-derived structural models of test area	"Average", 2-D structural model	Compare techniques Compare models Standardize format of geotechnical data Obtain "average" model structure
5) Measurement of Weak-Motion Across Test Area	September 1987	DMG/LLNL		Observation of ground motion, during small earthquakes, at sites R1, R2, V1, V2, D1, D2 and D3 (Figure 1)	Obtain recordings at site R1, to give to predictors Obtain simultaneous recordings at sites V1, V2, D1, D2, and D3 to use in Prediction Workshop I.
6) Preparation of Predictions of Site Effects for Weak-Motion and Hypothetical Strong-motion	Fall 1987 - Spring 1988	All interested parties	"Average", 2-D structural model of test area, from Geotechnical Workshop (and, if desired, raw geotechnical data to allow calculation of individual structural model) PLUS	A measure (e.g., transfer funtion, response spectrum, or time history) of ground motions at sites:	Demonstrate methods' dependence on:
Prediction A	....	....	recording of ground motion of small earthquake (event 1) at site R1	.... D1,D2,D3,V1, and V2	rock structure
Prediction B	....	....	recording of ground motion of a small earthquake (event 2) site D2	.... R1, V1, V2, D1	sediment thickness
Prediction C	....	....	hypothetical record of ground motion of a large earthquake (event 3) at site R1	.... D1,D2,D3,V1 and V2	input amplitude and rock structure
Prediction D	....	....	hypothetical record of ground motion of a large earthquake (event 4) at site D2	.... R1, V1, V2, D1	input amplitude and sediment thickness
7) Prediction Workshop I If large event was not recorded before Prediction Workshop I, then:	June 1988	All interested parties	Predictions A, B, C and D Observations of weak ground motion at R1, R2, V1, V2, D1, D2 and D3	Comparison of predictions and observations	Evaluate cost and accuracy of different methods of estimating geologic site effects
8) Next Parkfield Earthquake Measurement of Strong-Motion Across Test Area	?	SHIP/DMG		Observations of ground motion, during strong earthquake, at sites R1, R2, V1, V2, D1, D2, D3 (Figure 1)	Obtain recordings at site R1, to give to prediction Obtain simultaneous recordings at sites V1, V2, D1, D2 and D3, to use in Prediction Workshop II
9) Preparation of Predictions of Site Effects for Strong-Motion	Later	All interested parties	"Average", 2-D structural model of test area, (and, if desired, raw geotechnical data) PLUS	A measure (e.g., transfer function, response spectrum or time history) of ground motions at sites:	Demonstrate methods' dependence on:
Prediction E	....	....	recording of ground motion of a large earthquake (the next Parkfield M 6 event at site R1	.... D1,D2,D3, V1, and V2	input amplitude and sediment thickness
Prediction F	....	....	recording of ground motion of large earthquake (an aftershock of the next large Parkfield event) at site D2	.... R1,V1, V2, D1	input amplitude and sediment thickness
10) Prediction Workshop II	Still later	All interested parties	Predictions E and F Observations of strong ground motion at sites R1, R2, V1, V2, D1, D2, and D3	Comparison of predictions and observations	Evaluate cost and accuracy of different methods of estimating geologic site effects

FIGURE

SCHEDULE OF TURKEY FLAT, PARKFIELD, CALIFORNIA
GEOLOGIC SITE EFFECTS EXPERIMENTS



across the test site. The workshop will also agree on a format in which the average structural model as well as the raw geotechnical data will be provided to participants in the prediction phase of the experiment.

In September 1987, seismic field experiments will be conducted by DMG and Lawrence Livermore National Laboratory scientists. The purpose of these experiments is to record the ground motion of small, local and regional earthquakes at the sites R1, R2, V1, V2, D1, D2 and D3, shown in Figures 1 and 2. As described below, some of these recordings will be distributed to people wishing to predict the response of the Test Area, while some of the recordings will be withheld until they can be compared with predictions.

Preparations of the first group of predictions will take place from the Fall of 1987 to the Spring of 1988. Individuals making predictions will be provided with: 1) the "average" structural model of the Test Area derived from the Geotechnical Workshop, and 2) a record of ground motion at one site on the Test Area. Four predictions will be asked of each individual:

1) Prediction A- ground motion at sites D1, D2, D3, V1, and V2 given the actual recording of a small earthquake (event 1) at site R1;

2) Prediction B- ground motion at sites R1, V1, V2, and D1, given the actual recording of another small earthquake (event 2) at site D2;

3) Prediction C- ground motion at sites D1, D2, D3, V1, and V2 given a hypothetical recording of a large earthquake (event 3) at site R1;

4) Prediction D- ground motion at sites R1, V1, V2, and D1, given a

hypothetical recording of a large earthquake (event 4) at site D2.

Prediction of ground motion can take the form of one or more of the following:

1) the transfer function of a site relative to the given reference site (e.g., for Prediction A, the Fourier Transform of the motion at site D1, D2, D3, V1, and V2 divided by the Fourier Transform of the motion at site R1 (D1/R1, D2/R1, D3/R1, V1/R1, V2/R1); and for and for Prediction B, the Fourier Transform of the motion at sites V1, V2, and D1, divided by the Fourier Transform of the motion at site D2 (V1/D2, V2/D2, D1/D2);

2) the response spectra of the motion at sites in question; and

3) the ground motion time histories at the sites in question.

Each individual predictor <u>must</u> make one set of predictions using the "average" structural model. If, however, individuals wish to determine their own structural model and use it to make another set of predictions, raw geotechnical data will be provided.

Prediction Workshop I will take place in June 1988, where predictions and actual observations will be compared. On the basis of these comparisons, the cost and accuracy of the different methods for estimating geologic site effects on ground motion can be evaluated.

When the next Parkfield M5-6 event occurs, it and its larger aftershocks will be recorded on the SMIP strong-motion array at sites R1, R2, V1, V2, D1, D2, and D3 in the Test Area. These records will be used in the preparation of the second group of predictions:

1) Prediction E- ground motion at sites V1, V2, D1, D2, and D3, given the recording of motion of the main Parkfield event at site R1; and

2) Prediction F- ground motion at sites V1, V2, D1 and R1, given the recording of an aftershock at site D2.

If the next large Parkfield earthquake occurs well before June 1988, Predictions E and F will be discussed at the Prediction Workshop I. If the earthquake occurs after the Workshop I, a Prediction Workshop II will be held.

VI. POSSIBLE PROBLEMS

While it would be disappointing if the predicted event did not occur in the next few years, the absence of a large, nearby earthquake would not mean a failure of the experiment since the various methods' predictions will be compared with each other and with observations of weak motion. Such comparisons have not been systematically made before. In view of the historic record of seismicity on the Parkfield segment of the San Andreas fault and under the nearby Kettleman Hills-Coalinga Anticline, a moderate or large event will occur near the test area eventually.

Even if the site conditions at Turkey Flat are commonly found around the world, there are many other different site conditions that underly urban areas that are equally common. Thus, whatever conclusions are drawn from this experiment, they will be applicable only to a subset of all sites. Methods that work well at the Turkey Flat Test Area might not work well at other sites; methods that fail at Turkey Flat, might be adequate elsewhere. These limitations underscore the need to establish other test areas in California and elsewhere in the world, in places where other site conditions are present. Our experience in establishing a test area in California will be shared with geoscientists from other countries at the 1987 IASPEI meeting, for use in selecting other test areas.

The most serious problem would be if the experiments were designed poorly so that the results were inconclusive. Careful planning and the concerted effort of all participants will be necessary to avoid this problem.

VII. SUMMARY

A project is underway near Parkfield, California to test and compare the reliablity and cost of various methods used to estimate the effects of local soil conditions on earthquake ground motion. A systematic study of this kind is needed before methods can be used routinely to assess an area's potential for strong ground shaking and to incorporate the results into land use, design, and construction decisions on a regular basis. This need is not limited to California, but applies to all of the U.S. and many other areas of the world. The success of this project will require the broad, active support of the seismological, earthquake engineering, and earthquake planning communities throughout the world.